TITLE OF THE INVENTION

VARIABLE PASSBAND AUTOREGRESSIVE MOVING AVERAGE FILTER

BACKGROUND OF THE INVENTION

The present invention relates to filter designs, and more particularly to a variable passband autoregressive moving average (ARMA) filter using a non-causal filter design.

A problem common to several signal processing applications, including radio frequency (RF) tuning, audio tone controls, variable transient filtering, sampling rate conversion, jitter/wander compensation and/or measurement and the like, is that a zero-pole based digital filter, such as an infinite impulse response (IIR) and finite impulse response (FIR) combination, needs to have a variable frequency response at a given sample rate, or vice versa – constant frequency response at a variable sampling rate. In video there is such a need for a variable bandwidth video luminance filter in order to reduce sensitivity of transients seen by a signal out-of-range detector/alarm. Such a filter needs to have a nominal lowpass response, as given by IEEE-P205, and via one control parameter continuous range from full bandwidth to some small fraction of nominal bandwidth. An additional requirement is that the filter needs to have greater computational efficiency – faster/less expensive – than existing filter methods in order to have realtime performance in a video waveform monitor, for example.

Prior digital variable bandwidth filters include the use of:

1) either only FIR or only IIR filters;

2) analog filter simulation with variable C, L, R, gyrator, etc.;

3) discrete bandwidth selection of ARMA design.

The first class satisfies the continuously variable bandwidth requirement, but generally requires more computation to approximate a pole with many zeroes and vice versa. The second class also satisfies the continuously variable bandwidth requirement, but generally does not work well when the cut-off frequency approaches Nyquist – at which point instability may take place for higher order filters or extra processing may be required to prevent it. Also in the second class mapping the passband control parameter to new filter component values is not always readily apparent or may be difficult or impractical to implement. The third class does not satisfy the continuously variable bandwidth requirement.

What is desired is a stable, continuously variable bandwidth controllable via one parameter, digital filter for processing signals from full bandwidth to a small portion of the bandwidth.

BRIEF SUMMARY OF THE INVENTION

Accordingly the present invention provides a variable passband autoregressive moving average (ARMA) filter having as inputs a signal to be filtered, a reverse version of the signal to be filtered and a variable coefficient to produce as an output a filtered signal. The variable coefficient is generated by a variable equivalent sample rate coefficient converter (VESRCC) having as inputs an initial coefficient and a variable resampling rate parameter which controls the passband.

The objects, advantages and other novel features of the present invention are apparent from the following detailed description when read in conjunction with the appended claims and attached drawing.

BRIEF DESCRIPTION OF THE SEVERAL VIEWS OF THE DRAWING

Fig. 1 is a block diagram view of a variable “equivalent sample rate” coefficient converter for use in the present invention.

Fig. 2 is a block diagram view of an implementation of a variable passband ARMA filter according to the present invention.

Fig. 3 is a block diagram view of the implementation of Fig. 2 with gains redistributed according to the present invention.

Figs. 4a and 4b are plots of the frequency response of the ARMA filter using a first set of coefficients according to the present invention.

Figs. 5a and 5b are plots of the frequency response of the ARMA filter using a second set of coefficients according to the present invention.

Figs. 6a and 6b are plots of the frequency response of the ARMA filter using a third set of coefficients according to the present invention.

DETAILED DESCRIPTION OF THE INVENTION

The present invention is close to the second class of filter discussed above using an ARMA design. A variable equivalent sample rate recursive coefficient converter (VESRCC), shown in Fig. 1 and described in more detail in co-pending U.S. Patent Application Serial No. 09/925,546 filed August 8, 2001, is used which takes advantage of the bilinear transform to shift the

poles of the IIR filters. Referring now to Fig. 2 a variable passband ARMA filter **10** is shown that meets the IEEE P205 luminance filter specification (IEEE G 2.1.4/98-07: "IEEE P205 Draft Standard on Television Measurement of Luminance Signal Levels"). The architecture shown uses a sum of weighted first order IIR filters, similar to the "seagull" architecture disclosed in co-pending U.S. Patent Application Serial No. [DF 7773] filed March 17, 2004. X(n) represents an input signal (forward signal), and X(N-n) represents a reversed version of the input signal (reverse signal). The forward signal is input to a first IIR filter **20**, the reverse signal is input to a second IIR filter **30** in parallel with the first IIR filter, and the outputs from the two filters are combined with the input signal in a summing circuit **40**. The variable coefficients for the ARMA filter **10** are derived from initial filter values, $\mathbf{b_0}$ and $\mathbf{a_1}$, via respective VESRCC circuits **50, 60**, to which also are input an equivalent passband ratio, **R**. By varying the parameter **R** a continuous range from full bandwidth to some small fraction of nominal bandwidth is achieved.

Each IIR filter **20, 30** has an input gain stage in the form of an input multiplier **21, 31** to which the gain coefficient from an asymmetric VESRCC circuit **50** is input. The second stage is a decay stage where the output from the input multiplier **21, 31** is input to a summer **22, 32**, the output of which is input to a delay circuit **23, 33** that provides the output of the summer delayed by one sample time as the filter **20, 30** output. The output from the delay circuit **23, 33** also is input to a decay multiplier **24, 34**, the output of which is the other input to the summer **22, 32**. The decay coefficient from a symmetric VESRCC circuit **60** is input to the decay multiplier **24, 34**.

In an ARMA filter, such as that of Fig. 2, if the zeroes are shifted, misalignment of zero and pole related gains over frequency cause response distortions in the general case. For example, higher frequency stop band attenuation may suffer as the zero shifts lower in the frequency domain. However if for zeroes the bilinear transform based on the scaling method implemented by the VESRCC circuits **50, 60** is applied above a nominal frequency resampling rate, corresponding to a resampling rate R>1.0 in the above-mentioned co-pending application 09/925,546, the response distortion is mitigated. Below the nominal resampling rate (R<1.0), the zeroes no longer shift, but instead are nominal. This allows the advantages of the VESRCC circuits **50, 60**, as cited in the co-pending application, while solving the problem of zero/pole gain mismatches, such as stop band attenuation reduction mentioned above. The present invention uses the asymmetric (R>1.0 only) use of the VESRCC circuit **50** on zeroes only, and the symmetric (all values of R) use of the VESRCC circuit **60** on poles.

As shown in Fig. 2 the gain of the filter **10** is not unity, but may be made unity gain simply by adding a multiplier and appropriate gain correction at the output, as shown in Fig. 3. In this implementation the IIR filters **20', 30'** only have the decay stage described above. An "all pass" multiplier **41** for the input signal replaces the individual gain multipliers **21, 31** of Fig. 2. The all pass gain coefficient input to the all pass multiplier **41** is a function of **R**, and the output is input to the summing circuit **40**. The output from the summing circuit **40** is input to an output multiplier **42** which has a gain correction coefficient as a function of **R**. The output of the output multiplier **42** is the

filter **10'** output. The **allPassGain(R)** = $(1-a_1'(R))/(b_0'(R))$ to maintain the ratio of gains between the all pass portion and each IIR portion, and **gainCorrection(R)** = $(1-a_1'(R))/(2-\text{allPassGain}(R))$ sets the overall filter gain.

The filter design described above has resource savings advantages when implemented in either hardware, such as field programmable gate arrays (FPGAs), or in software in a digital signal processor (DSP) or general purpose computer processing unit (CPU) such as found in personal computers (PCs). Although the specific implementations shown here use a non-causal filter design, the variable rate solution may be applied to causal filters as well, thus being applicable to digital ARMA filters generally. In the non-causal version described herein, the filter design may also be applied generally to the filtering of signals for any application which processes signals in segments, records, etc. such that bi-directional filtering may be used. Thus all measurement instrument displays of plots of data, such as voltage vs. time, magnitude and phase vs. frequency, video and audio displays, etc. may use this filter design. The filter design has all the advantages of using the VERSCC circuit while maintaining passband and stop band characteristics over bandwidth control. As a result an efficient filter may be used with a relative passband control mechanism.

Figs. 4a and 4b show respectively a plot of frequency response for the filter design described here with an IEEE P205 luminance filter template and the same plot zoomed in near zero dB. The coefficients for this implementation are:

$\mathbf{b_0} = 1$, $\mathbf{a_1} = 0.53$, **allPassGain** = 1.1494253, **gainCorrection** = 0.1850226, R = 1

Figs. 5a and 5b show the same plots as above, but the coefficients are (due to R = 2 for double the bandwidth):

b_0 = 1, **a_1** = 0.2384493, **allPassGain** = 2.3008849, **gainCorrection** = 0.2029589, R = 2

Figs. 6a and 6b show the same plots as above, but the coefficients are (due to R = 0.5 for half the bandwidth):

b_0 = 1, **a_1** = 0.7336897, **allPassGain** = 1.1494253, **gainCorrection** = 0.1154806, **R** = 0.5

Thus the present invention provides a variable passband ARMA filter by combining a variable equivalent sample rate coefficient converter (VESRCC) with a digital filter having a seagull architecture using parallel IIR filters, the outputs from the IIR filters being combined with the input signal to produce the filter output and the variable passband being controlled by a single sample rate parameter to generate filter coefficients from initial coefficients.